Estimating Software Reliability In the Absence of Data

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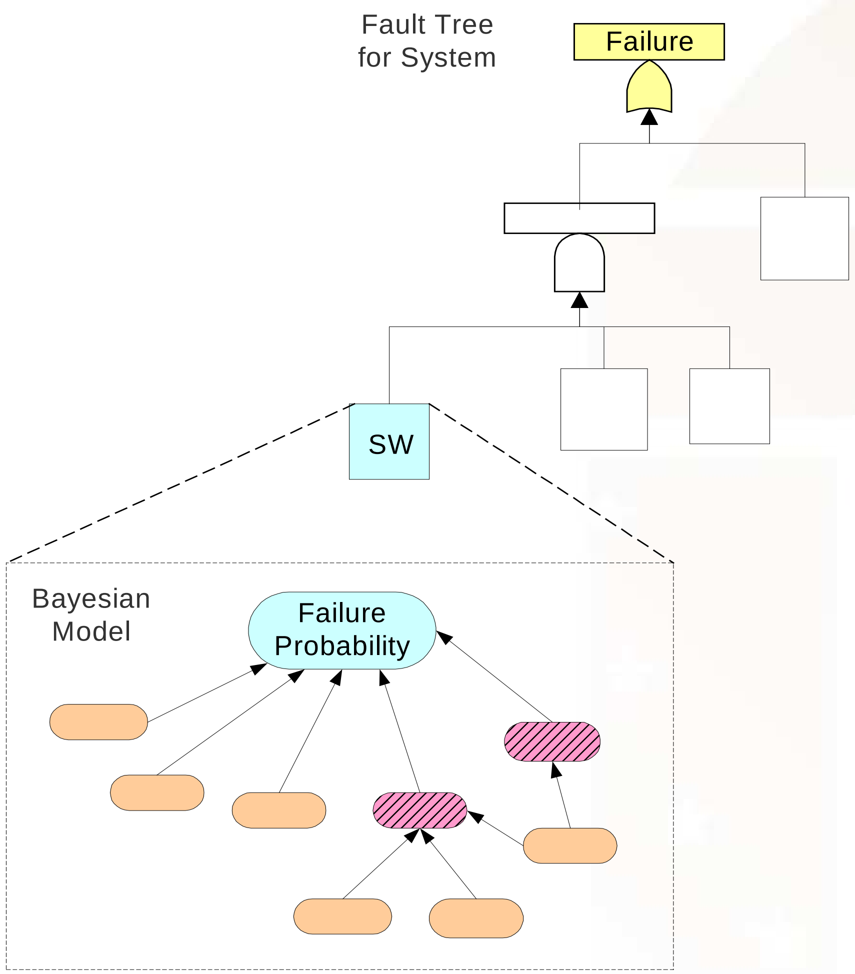
Research Motivation

- Estimate of reliability of systems containing software
- How do we do this early during design?
- Many quantitative approaches to estimate software reliability rely on test data
  - Test data may not be available till late into the project
  - Process information is available which is usually not considered in the reliability estimate
- Develop a reasonable "first-pass" prediction when little or no data is available
- Provide confidence in the reliability estimates

Proposed Approach

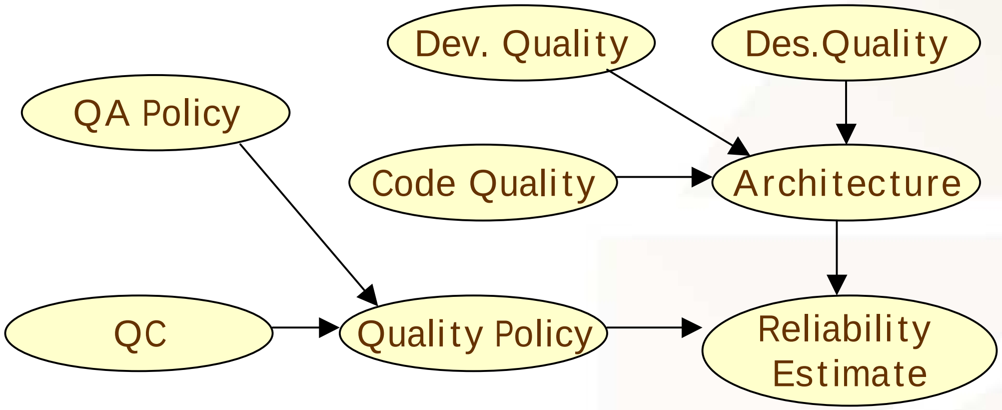
- Develop a generic bayesian model (BBN) based on software development lifecycle
  - Capture the influence of development processes on software reliability
  - Provide a "first pass reliability estimate"
  - Refine BBN & Reliability Estimate as testing data / lifecycle / process information is available
- Inputs to the bayesian network would be
  - Metrics available early during design
  - Insights from the software architecture
  - Expert insights/ engineering judgment
  - Knowledge of module quality from quality classification
  - Other insights *i.e.* Were formal methods used?, etc.
- Possible outputs
  - A probability that the software reliability lies in a certain range
  - Confidence value that the software reliability has an acceptable value
  - An estimate of # of residual faults

Proposed Approach – A Bigger Picture



- Use a point estimate from the predicted range in the BE for a fault tree of the system
- The fault tree provides an estimate for system unreliability, taking software into account
- Related work by Smidts *et al.* at UMD
  - We are not developing a FT for software
  - Rather develop FT for the entire system, where software is a basic event
  - No enumeration of process failure modes
  - If available, can be incorporated
  - They note that a bayesian framework incorporating history and combining qualitative and quantitative information will be valuable

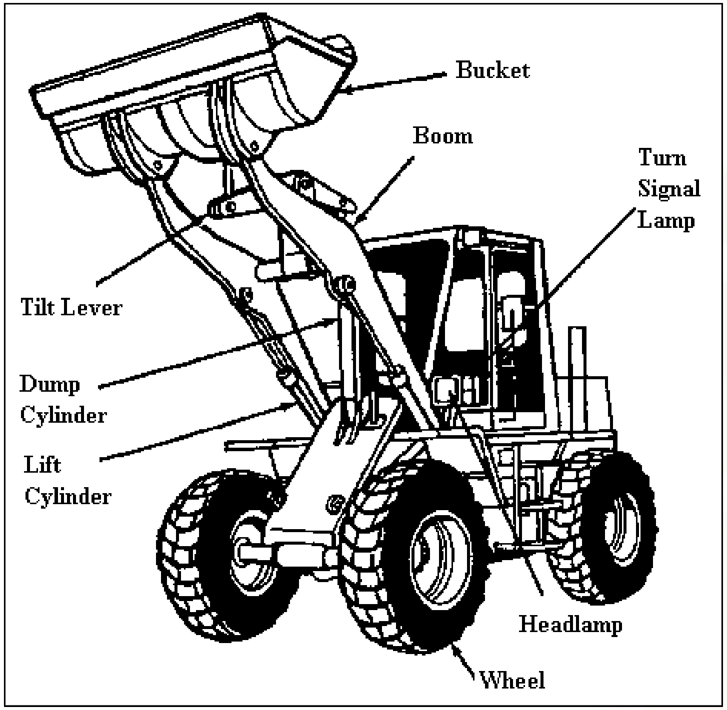
Bayesian Belief Networks and Fault Trees



- BBNs are a directed acyclic graph with nodes and edges
  - Nodes represent random variables with probability distributions
  - Edges represent weighted causal relations between nodes
  - Graphical representation of probability propagation using Bayes' formula

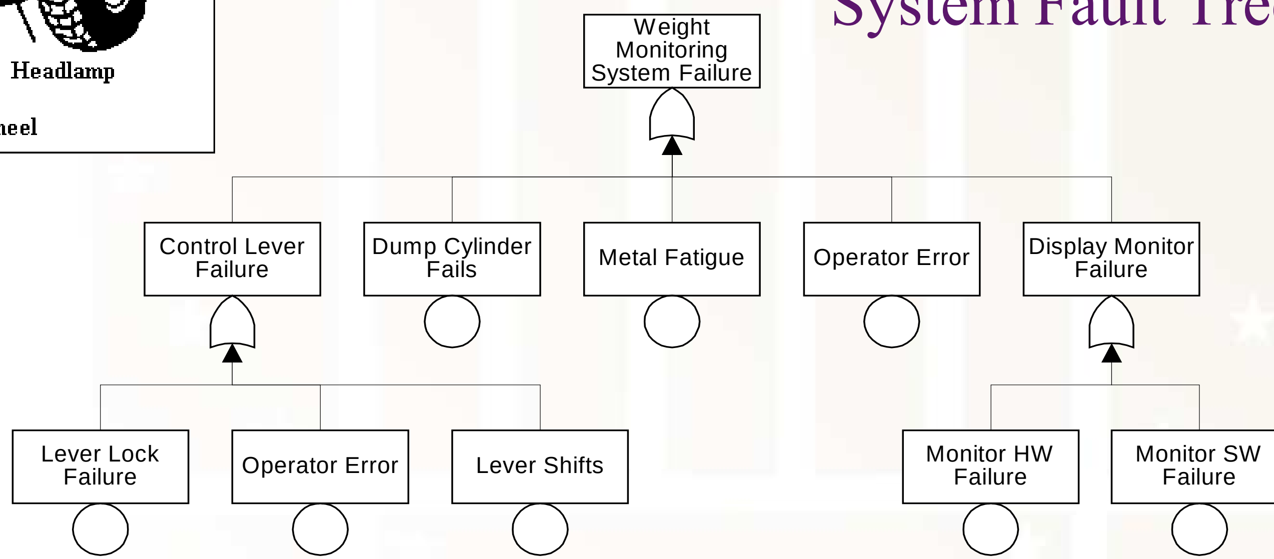
- Fault Trees are a graphical representation of logical relationship between
  - Basic failure events (BE) and System failure (Top event)
  - Have Static / Dynamic gates
  - Computes P(Top Event) as a function of P(BE)
- Can express combinatorial and non-combinatorial failures

Example

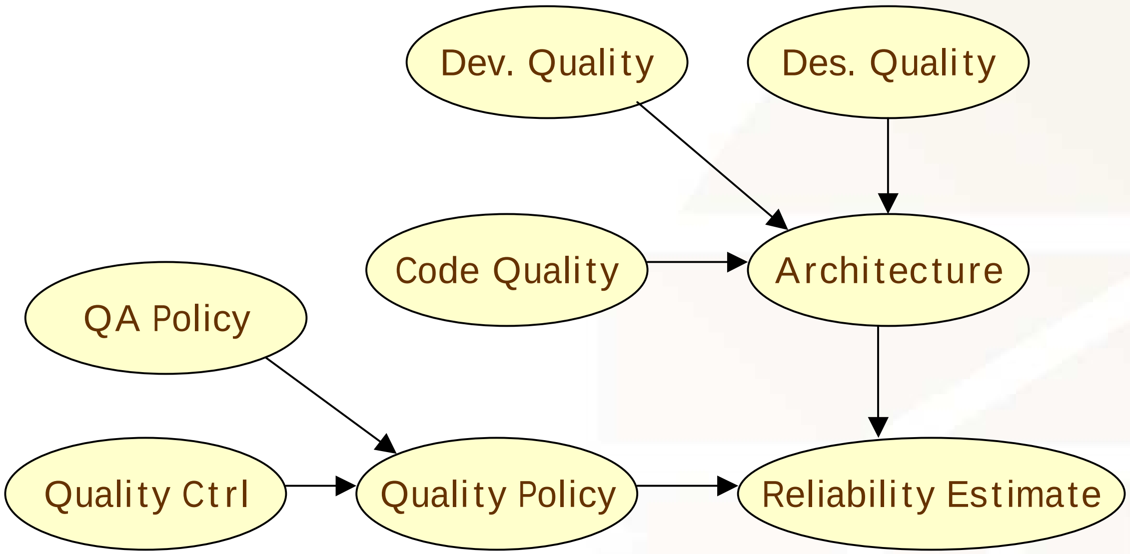


- Front end loader with a software controlled weight-monitor system
- System reports weight of load to the operator
  - — Incorrect reporting can cause failure of hydraulic system
  - — Loader may tip over if (weight of load) > Max. permissible load

System Fault Tree



Hypothetical BBN for Software



- Node probability tables associated with each node
- Each node can have multiple states
- NPT of a Node A with parents B, C → $P(A_i / B_j, C_k)$
- NPTs define the "weight" of the causal relations between nodes4

Deterministic NPT for Quality Policy

QA	QC	QP
Strict	Strict	Superior
Strict	Poor	Medium
Medium	Strict	Superior
Medium	Poor	Medium
Mediocre	Strict	Medium
Mediocre	Poor	Mediocre

AQ	QP	HigherR...	Middle...	LowerR...
Superior	Superior	100.00	0.000	0.000
Superior	Medium	80.000	20.000	0.000
Superior	Mediocre	15.000	70.000	5.000
Medium	Superior	5.000	90.000	5.000
Medium	Medium	5.000	80.000	15.000
Medium	Mediocre	0.000	25.000	75.000
Inferior	Superior	15.000	70.000	5.000
Inferior	Medium	0.000	5.000	95.000
Inferior	Mediocre	0.000	0.000	100.00

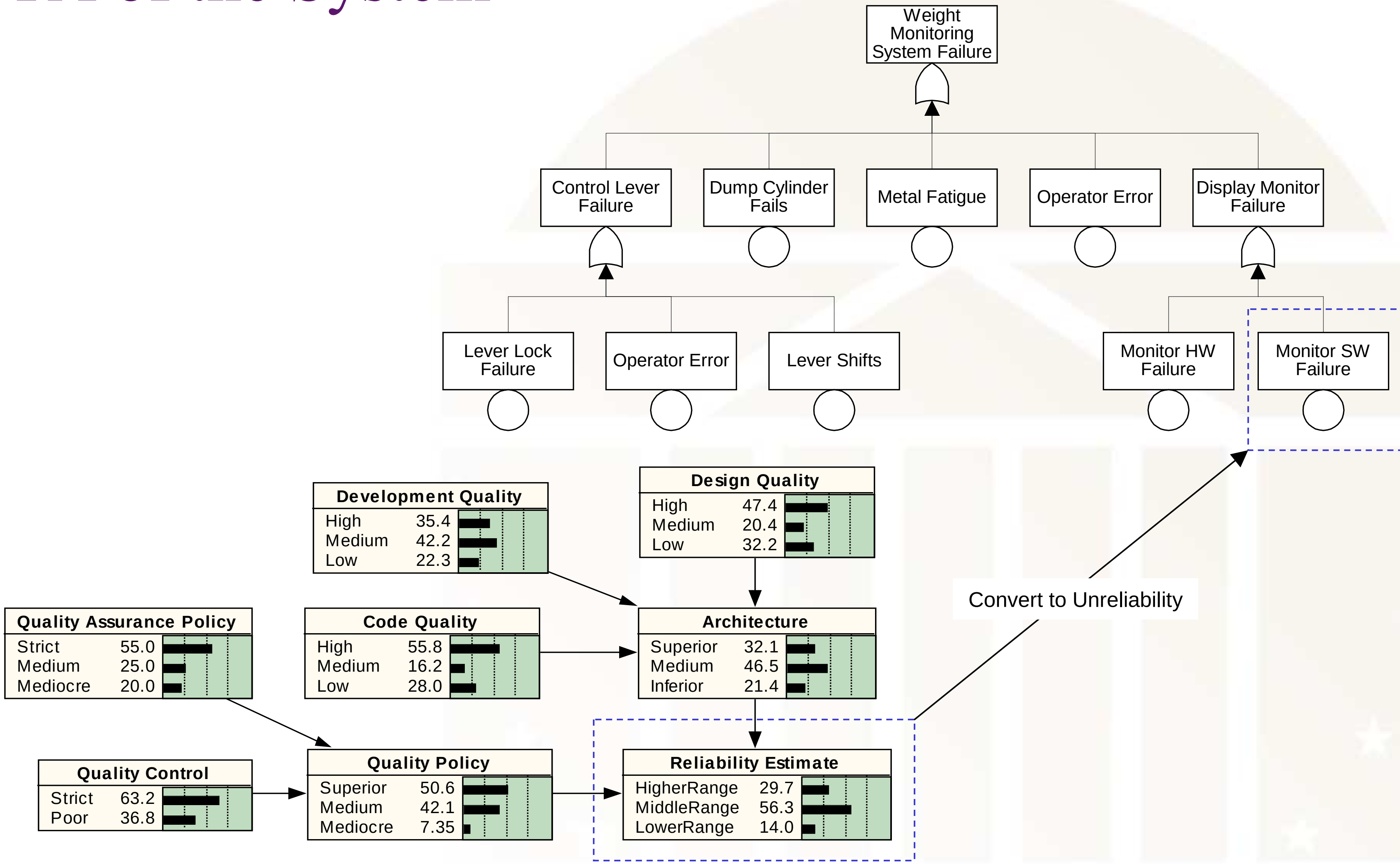
Hypothetical BBN for Software (Cont'd.)

- Hypothetical priors are computed
  - After gathering data, instantiating parent nodes
  - Transition weights are determined by expert judgment
  - *Reliability Estimate* states represent $R > 0.95$; $0.95 \leq R \leq 0.9$; $R < 0.9$

Computation of Priors

- For a variable A with states $a_1, a_2, \ldots, a_n$; (Root nodes in the BBN)
  - $P(A)$ = Probability distribution over the states = $P(a_1, a_2, \ldots, a_n)$;
  - $a_i \geq 0$; $\sum_{i=1}^{n} a_i = 1$
- For another variable B with states $b_1, b_2, \ldots, b_m$; (Child/ Target node)
  - $P(A / B)$ is an $n \times m$ table containing numbers $P(a_i / b_j)$
  - This is the NPT in the BBN
  - Also $P(a_i / b_j)\, P(b_j) = P(a_i, b_j)$ *and* $P(a_i) = \sum_{j=1}^{n} P(a_i, b_j)$
  - Finally $P(A) = \sum_{B} P(A, B)$
  - The BBN is an elegant graphical abstraction for this computation

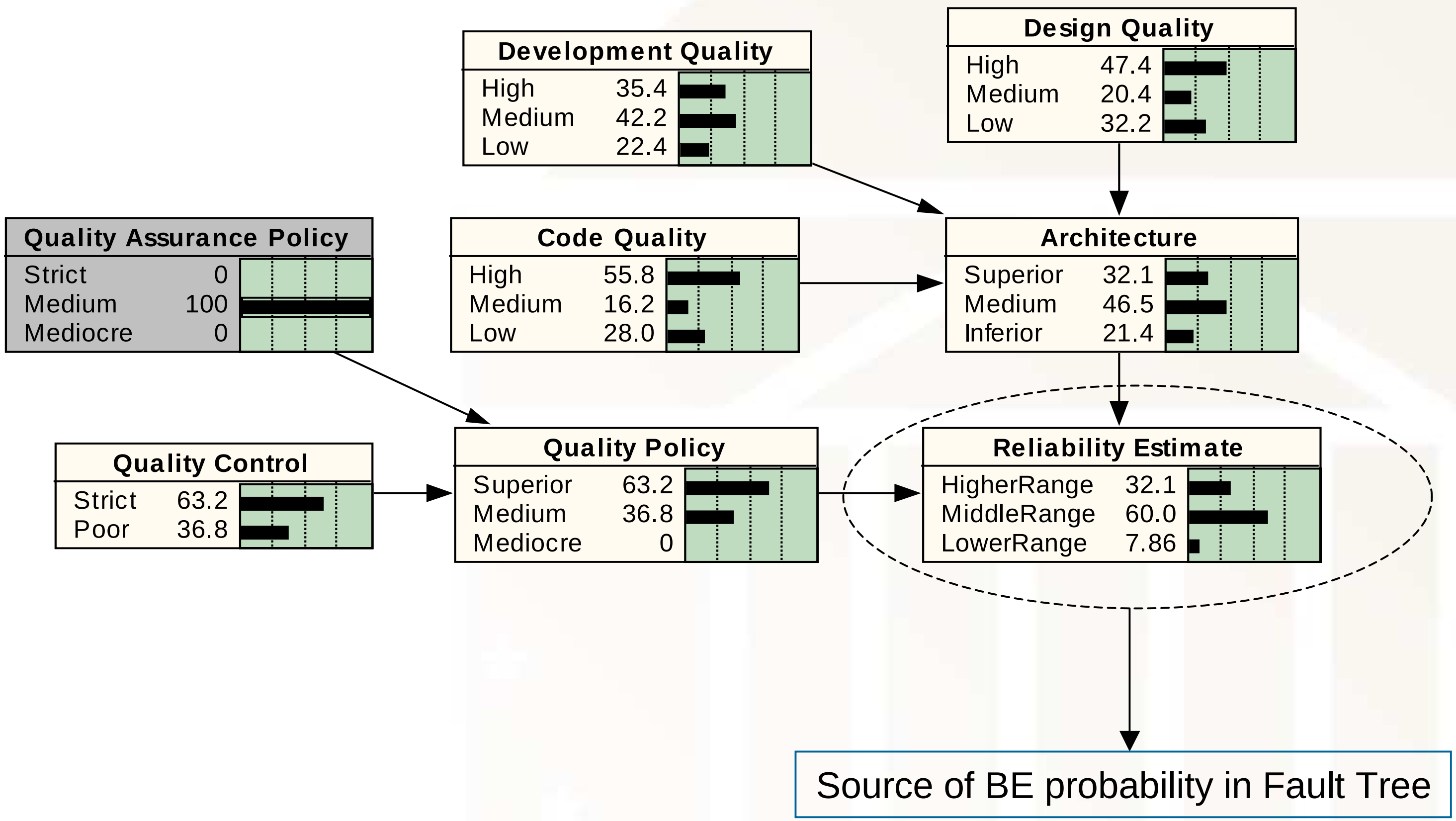
FTA of the System



Analysis – Result of FTA

Basic Event	Failure Rate (λ)	Failure Probability (P)	System Unreliability (Q)
Lever Lock Failure	0.0045	-	*0.66103*
Operator Error	-	0.03	
Lever Shifts	0.00065	-	
Metal Fatigue	0.0035	-	
Monitor HW Failure	0.00000565	-	
Monitor SW Failure	-	0.1	

Analysis - Effect of Evidence



Comparison

Reliability Estimate before evidence

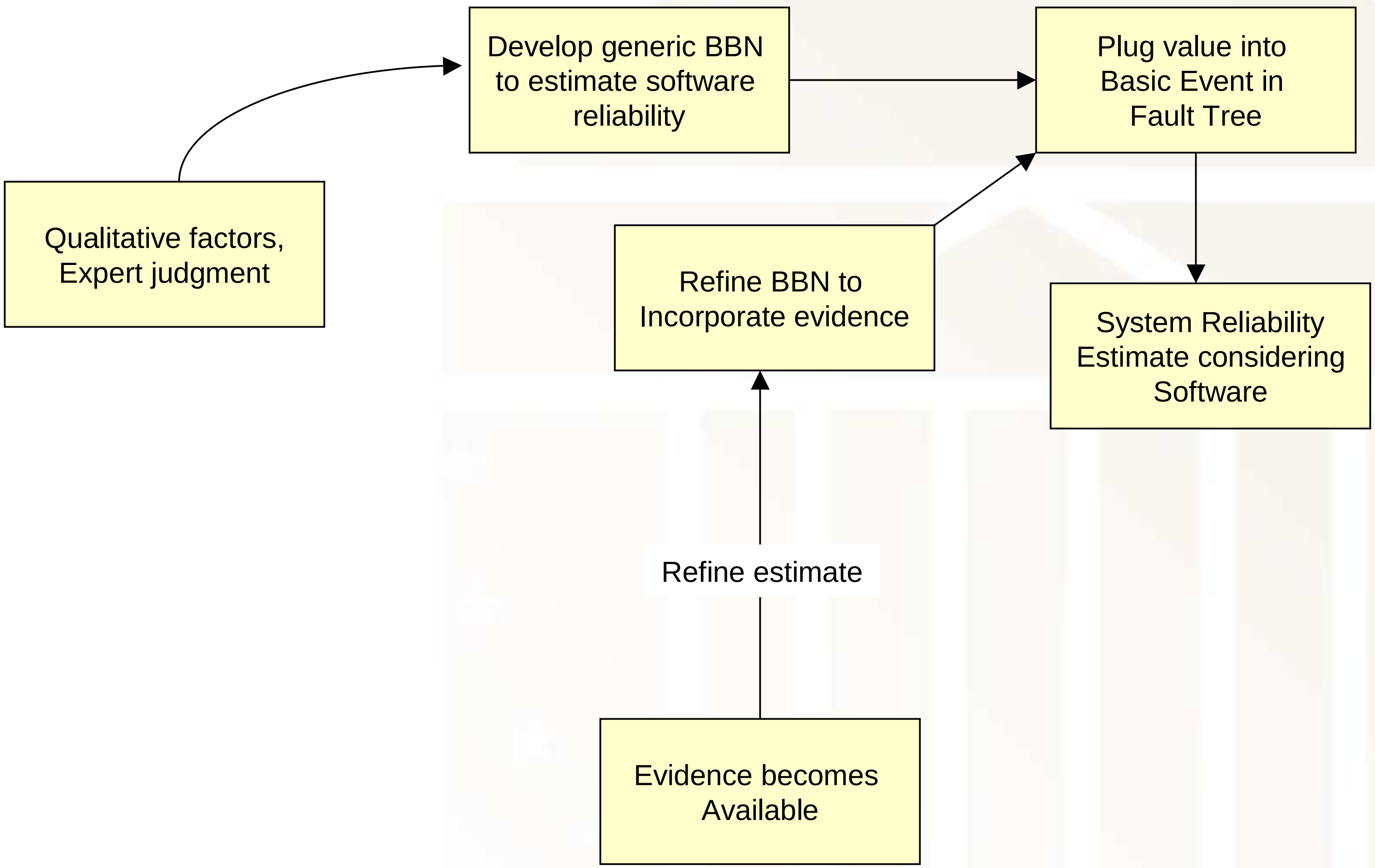
Reliability Estimate	
HigherRange	29.7
MiddleRange	56.3
LowerRange	14.0

Reliability Estimate	
HigherRange	32.1
MiddleRange	60.0
LowerRange	7.86

Reliability Estimate after evidence

- Evidence has increased probability of $0.95 \leq R \leq 0.9$
- Point estimate is unchanged ➔ Result of FTA is the same
- However, we now have more confidence in this estimate
- Future work – quantifying the confidence value

Summary of the Methodology



Conclusions

- Process and product information / evidence is incorporated as they become available.
- Reliability estimates can be refined
- The Bayesian framework provides confidence in the reliability estimates
- An early estimate of reliability - by blending qualitative data, expert opinion/ engineering judgment with quantitative data

Future Work

- Developing a generic BBN based on software lifecycles
- Identifying nodes of the BBN
- Determining NPT values
- Define a stopping criterion for adding BBN nodes

Especially interested in getting real data to validate methodology
Please let us know if you'd be willing to share data!

Contact

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Project

Modeling the "Safe Enough to Release" Decision

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Validation of System Safety

Validation of system safety is the process by which it is determined that the system, as designed, can be expected to operate without incident for a given time period within the specified requirements for safety.

The Problem

Current methods of validating safety may lead to the certification of a system as “correct,” “valid,” and “safe” when all *known* failure states have not been observed or tested in significant numbers.

The Problem

- How can an assessor extend the validation process to gain a greater confidence that the system is "safe enough"?
- What support is available to allow an assessor to weigh and review both quantitative and qualitative evidence in a systematic, repeatable, and auditable fashion?
- How can uncertainty be factored explicitly into the assessment?

In general...

How do we go from... to...

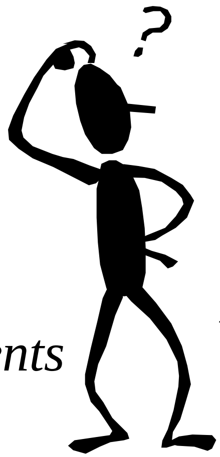
Is the system safe enough?

Test Results

Quality Assurance

Requirements Review

FTA



Personal and Team CMM

Prototype Performance

System Design

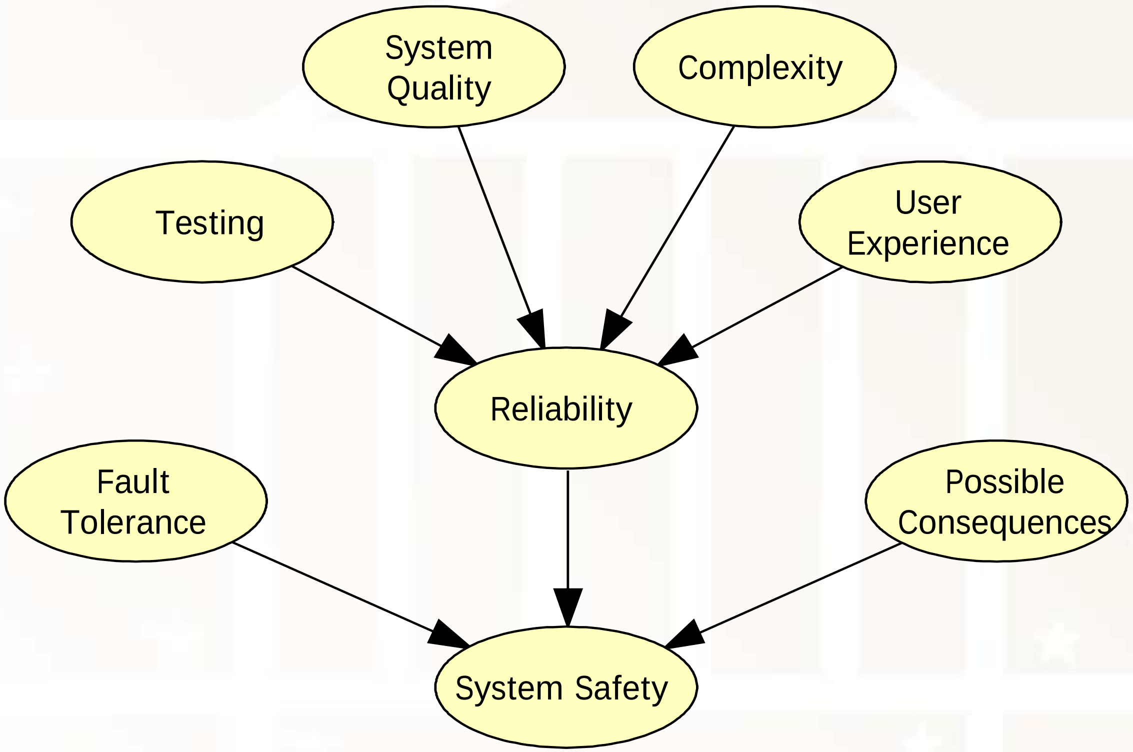
I have an acceptable level of belief that the system will operate as specified.

How can we bridge the gap between what we know and the requirements we must meet with the information that's available? ESPECIALLY WITH A UNIQUE SYSTEM?

One Possible Answer

Bayesian Belief Networks are a modeling formalism that support the proposed extension of the safety validation process.

A BBN from the Halden Project



Modeling Component Sources

Evidence comes primarily from:

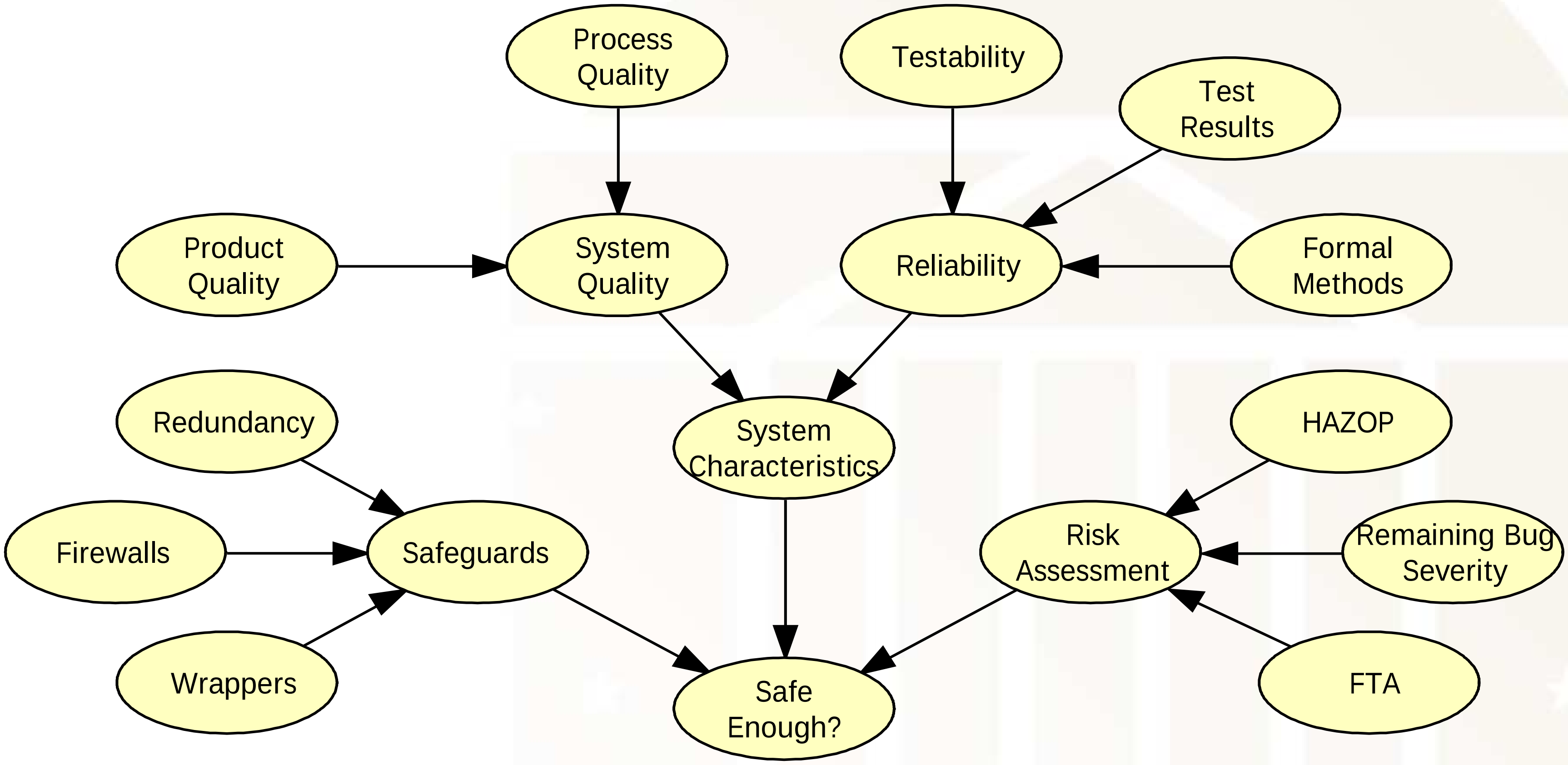
- Process Evidence
- Product Evidence
- Engineering Judgment

Modeling Components

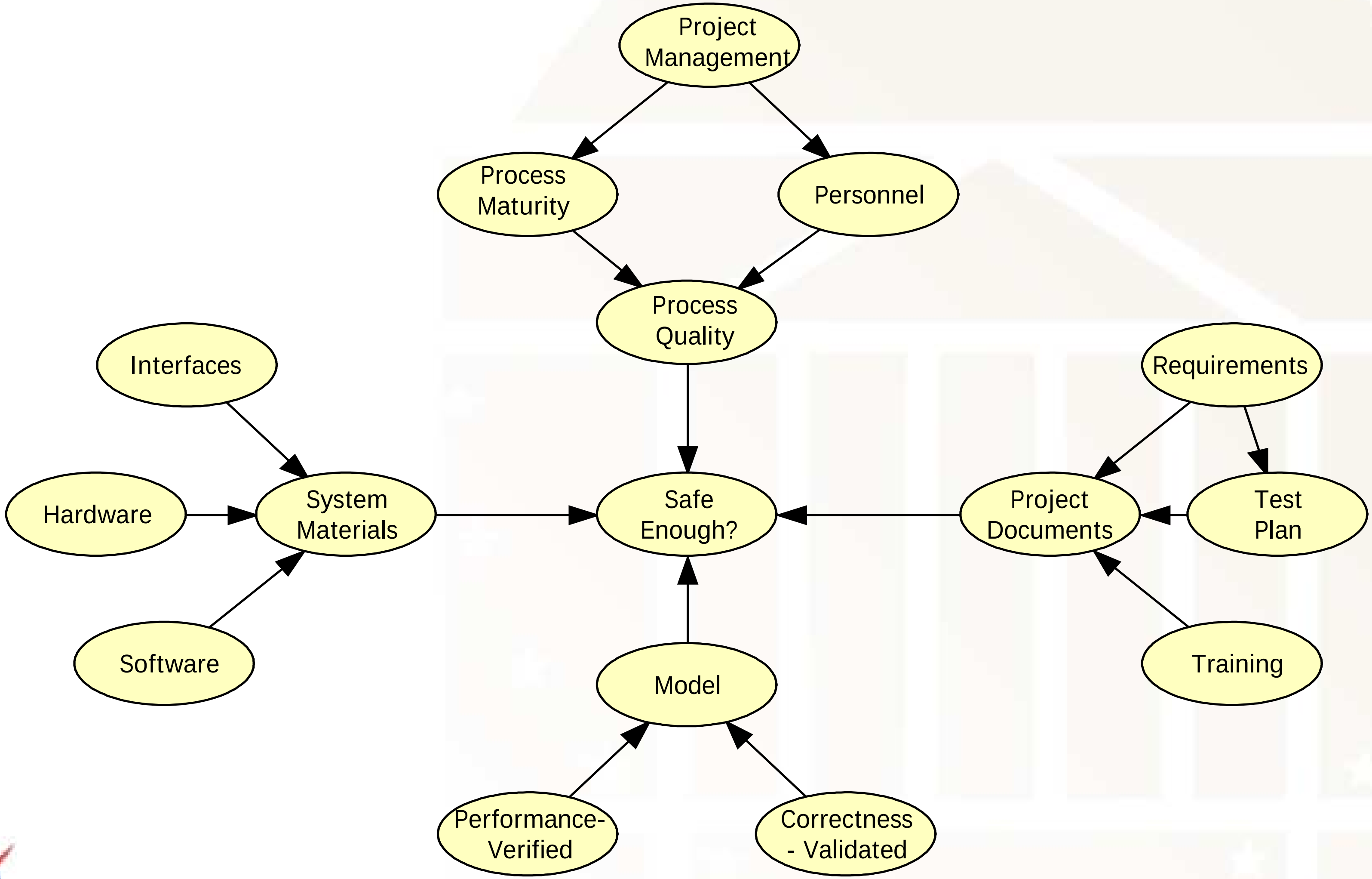
Variables to investigate and assess include:

- Dependability
- Quality (e.g., system, process, and supplier)
- Hazard / Risk Analysis
- System Design
- Compliance to Standards
- Results of V&V Activities
- "Safeness" of System Components and Interfaces
- Support Materials (e.g., training materials and project documents)
- Behavior of Prototypes or Simulation

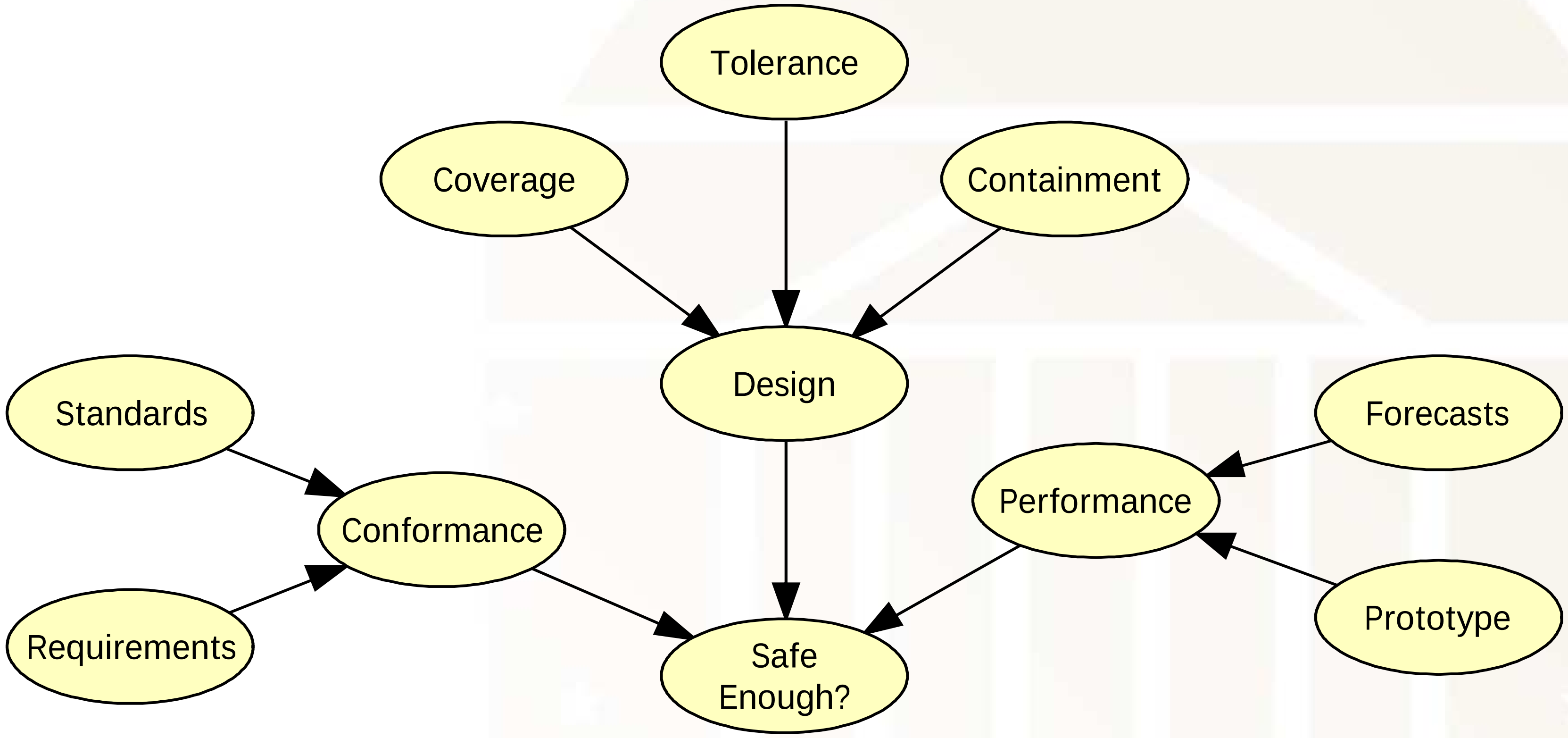
Proposed BBN (1)



Proposed BBN (2)



Proposed BBN (3)



Conclusions

Our examples represent the first step in modeling the assessment of the safety validation process for a generic, unique ultradependable computer-based system.

Results will vary depending on the system being modeled, BBN components, and the expert opinion elicitation methods.

Future Work

- Elicit expert opinion to populate BBN nodes' NPTs
  - Develop elicitation instrument
  - Evaluate usefulness of approximate reasoning and fuzzy intervals in elicitation
- Provide importance factors for nodes and paths
  - Adapt FTA importance factors
  - Develop new importance factors
- Develop case studies
  - Validate models against past projects
  - Apply models to current projects

Publications / Conferences

"Assessing the Results of System Safety Validation Using BBNs." Presented at PSAM6 (23 – 28 June 2002).

"Modeling the 'Good Enough to Release' Decision." Preliminary acceptance to RAMS 2003.